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INFLUENCE OF PARTICULATE REINFORCEMENT ON DAMPING AND ELASTIC MODULUS OF POLYMER COMPOSITES FOR MACHINE TOOL STRUCTURAL APPLICATIONS

VIJAYA HOLLA[1], VIVEK ANANDA[1], KRUPASHANKARA M. SETHURAM[2]

1. Undergraduate Student, Department of Mechanical Engineering, R.V.College of Engineering, Bengaluru, India.
2. Professor and Dean, PG (non-circuit), R.V.College of Engineering, Bengaluru, India

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Abstract: - Structural material used in the manufacture of the machine tool base has a pivotal role in deciding the surface finish, tool life and the dimensional tolerance that are achievable on the machine. Damping ratio and elastic modulus are the crucial properties for machine tool structural materials. Particulate reinforced polymer composites, when used as fillers in machine tool structure have resulted in improved damping behaviour with a resulting enhancement in the quality of the machined parts. In this study, the influence of the composition of particulate material, particulate size, its distribution and resin mass fraction on damping and elastic modulus were investigated by employing impulse hammer vibration test. In comparison to cast iron, the particulate reinforced polymer composite exhibited 20 times higher damping ratio with 5-10 times reduced elastic modulus. Among natural sand, marble, quartz and granite powders, natural sand had 15% superior properties due to its surface morphology and better resin-particulate interface. The particulate size distribution in the range of 0.1 to 0.5 mm gave 40% higher damping ratio with 25% variation in elastic modulus. The damping ratio increased linearly with resin mass fraction and it follows the ‘rule of mixtures’ law for polymer composites.It was found that butadiene powder can be used as secondary reinforcement along with high stiffness particles to control damping and elastic modulus properties.

Keywords: Polymer Concrete, Particulate Reinforcement, Damping, Machine Tool Vibration, Butadiene Reinforcement

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Corresponding Author: MR. VIJAYA HOLLA

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INTRODUCTION

Vibration in machine tool causes adverse effect on surface finish, tool life and hence on its precision.[1,2] Structures of the machine tool play a decisive role in absorbing the vibration and hence enhancing the precision as it shares the major part of the total machine tool mass. Due to increased demand for high precision machine tools, machine tool manufacturers and researchers are focusing on hybrid structures which are a combination of cast iron, alloy steels and polymer composites in order to enhance the vibration damping and improve its performance characteristics.[3-7] In this regard, particulate reinforced polymer composites have been proved to be the promising material. It is increasingly used in different parts of the structures such as bed, column, guide ways, spindle etc because of its superior vibration damping, moderate stiffness, ease of production, high strength to weight ratio, workability, chemical resistance and low thermal conductivity.[5-9] It has also been used as hybrid structure along with the high stiffness materials such as steel and carbon epoxy composites for machine tools. [10-12]

The properties of the polymer composites are determined by its reinforcement and matrix. For precision machine tool structural application, good elastic modulus and high vibration damping are the major requirements.[13] The works carried out to study the influence of composition in particulate reinforced polymer composite reveal that the damping ratio is influenced by reinforcing particles' size and mass fraction.[9,13-15] Increasing resin mass fraction up to 15% increased the damping ratio. Elastic modulus and compression strength were found to increase with increasing resin mass fraction up to 10%. [13] Literature survey shows that there are limited number of studies conducted on the influence of resin matrix with mass fraction more than 20% and on different particulate reinforcement materials, its influence on damping ratio and elastic modulus. In this study, influence of the composition and particulate size of reinforcement materials has been investigated. In addition the effect of resin mass fraction, in the range of 10-40%, has been evaluated.

PREPARATION OF TEST SPECIMENS

Sourcing of Raw materials

Natural sand, quartz powder, granite powder, marble powder and butadiene powder were used as the particulate reinforcements. Natural sand, granite powder were sourced locally while marble powder and quartz powder were procured from M/s Shiva Marbles and M/s Master Micron Ltd, Bangalore, India. Butadiene powder was purchased from M/s Omshree

Rubbers. Epoxy resin (LY556), which has been used as matrix material was purchased from Zenith Industrial Supplies, Bangalore, India

Preparation of Test Specimens

The reinforcing particles were cleaned, dried and sieved to the required particle size range. Polymeric resin and particles were thoroughly mixed in pre-determined proportion and poured into metal mould with the required dimensions of 25x25x20 mm. The poured mixture was allowed to cure for 24 hours at atmospheric temperature. The specimens were de-moulded and finished using fine grit sand paper. The composition of the test specimens are given in Table1.

TESTING OF THE POLYMER COMPOSITE SPECIMENS

Modal analysis with free-free boundary condition was carried out on the specimens by using impulse hammer vibration testing facility. The test set-up is shown in fig.1. Damping ratio was determined by 3-dB method. Elastic modulus was calculated from the results acquired by the impulse hammer test by employing equation 1 of free-free boundary condition.

$$E = \frac{\rho A}{I}\left(\frac{2\pi f l^2}{22.4}\right)^2 \quad \text{...(1)}$$

Where E is elastic modulus in N/m^2 ρ is density in kg/m^2, A is sectional area in m^2 and I is the moment of inertia in m^4, f is first bending mode frequency in Hz, l is length of the specimen in m.

During the test, a 4-channel FFT analyser, an impulse hammer, an accelerometer, and a force transducer were employed as shown in the Fig 1. The accelerometer records the displacement response from the specimen. The FFT analyser transforms the signal acquired from the accelerometer from time domain into frequency domain as shown in Fig 2. The damping ratio is computed by 3-dB method from the curve obtained in frequency domain.

RESULTS AND DISCUSSIONS

Influence of the Composition of Particulate Material

Results obtained for polymer composites with different reinforcing materials are compared with cast iron, alloy steel specimens in Table 2. Polymer composites with marble powder, quartz powder, granite powder and natural sand reinforcement have shown values of damping ratio ranging from 1.1+/-0.2%, with elastic modulus in the range of 10-20 GPa. However butadiene reinforced polymer composite exhibited a damping ratio of 3.4% and an elastic modulus of 0.24 GPa. Butadiene powder is a highly viscoelastic polymer by nature and hence possesses large inherent vibration damping with poor stiffness [17]. This could be the reason for high damping ratio with low elastic modulus exhibited by butadiene reinforced polymer composite. In comparison to cast iron, polymer composites have shown 20 times higher damping ratio and 6-8 times lower elastic modulus as shown in Table 1.

Examining the nature of reinforcing particles shows that quartz powder, marble powder, granite powder and natural sand belong to the same group of rock powders possessing large stiffness (Elastic modulus 60 to 80GPa,)[16]. As evident from the Table 2 these specimens have different densities and natural frequencies. There is nearly 40% variation in density values of these test specimens. These variations in densities and the resulting variations in the damping ratio and elastic modulus can be attributed to the particle size distribution, packing density and the wettability of the powders with the polymeric resin as shown in Fig.3. The interface between the particulate reinforcement and the polymeric resin does influence the damping and modulus values.

The particulate size distribution, resin fraction and the surface morphology are synergic parameters in governing the interfacial bonding and adhesion force between the particulates and the polymeric resin. The mechanical properties such as damping ratio and young's modulus are significantly influenced by the interfacial bonding between the particulates and polymeric resin. Sand appears to have smooth surface and hence allows effortless flow of polymeric resin as shown in Fig 3. This results in lower viscosity during mixing, which leads to formation of higher adhesive bonding between the surface of particulates and resin. This level of gripping leads to higher value of damping ratio (1.3%) with a corresponding lower level of elastic modulus of 10 GPa. Quartz, marble and granite seem to have an irregular texture due to the mining and crushing process involved which leads to comparatively higher viscosity while mixing. This situation leads to difficulty in resin to flow between the particulates resulting in lower adhesion bonding mechanism between the particulates and resin and lower damping ratio. Hence powder surface characteristics appear to have a significant influence on the damping ratio and elastic modulus.

As shown in Fig.4 the polymer composite dampens vibration by releasing the associated mechanical energy at 10 times faster in comparison to cast iron. In order to understand the influence of reinforcement and matrix material on the resulting polymer composite, damping ratio and elastic modulus of marble and resin were evaluated. The specimen made of polymeric resin showed 3.36% of damping ratio whereas marble showed 0.417% and the polymer composite exhibited 1.1% as shown in Fig 5. Elastic modulus of marble and resin were 70GPa and 2GPa respectively. Hence it is evident that the resin matrix a t of the vibration energy and hence provides damping to the polymer composite whereas high stiffness particulate reinforcement contributes to the elastic modulus. So it can be inferred that the inherent stiffness and damping ratio of reinforcement and matrix material influence the final property of the resulting polymer composite.

Influence of Particle Size

Figure 6 shows that the polymer composite with particles of size 0.1-0.5mm has nearly 40% higher damping ratio compared to polymer composites with < 0.1mm and 0.5-2 mm. However, the elastic modulus was only 10% lower. The void content in all the cases were <1%. This suggests that polymer composites with a particle size in the range of 0.1 to 0.5 mm would be preferred choice as filler material for improving the damping characteristics of machine tool structures. Therefore since particulate reinforcement provide stiffness in the polymer composite, as the packing density is maximized, inter-particulate space will be reduced and hence larger part of polymer composite is filled with stiff particles which result in increased elastic modulus in the polymer composite due to contact mechanism[13].

Influence of Resin Mass Fraction

Results presented in Fig 7 shows that increasing the resin mass fraction from 10% to 40% increases the damping ratio by 60% and reduces the elastic modulus by 45%.

The primary source of damping in polymer composites is the inherent high damping of the resin matrix as given in Fig 4. From the microscopic point of view, due to viscoelasticity, polymeric resin molecule chains convert the associated mechanical energy into heat energy and thus dampen the vibration by the process of stretching, bending, scissoring and twisting. Hence as the resin mass fraction is increased, damping ratio of the polymer composite enhances due to increased vibration absorption by the viscoelastic effect in the polymer composite. But as the resin mass fraction is increased, amount of reinforcement to provide stiffness reduces and hence elastic modulus of the polymer composite is decreased.

An interesting phenomenon was observed in the trend line of damping ratio is that the damping ratio follows the 'Rule of Mixtures' in polymer composites. The equation can be expressed as:

$$\eta_{PC} = \eta_R w_R + \eta_M w_M \quad \text{......(2)}$$

Where η_{PC}, $\eta_{R,}$ η_M is the damping ratio of polymer composite, pure particulate material and pure polymeric resin respectively. w_R and w_M is the weight fraction of particulates and polymeric resin used. This suggests that the composition of the polymer composite can be modelled to obtain the required damping ratio properties.

CONCLUSIONS

Particulate reinforced polymer composites are being used for machine tool structures. However, with the demand for high speed machines and special purpose machines increasing there is a need to develop specific formulations of polymer composites with desired damping ratio and modulus. This study has revealed that natural sand with a particle size distribution of 0.1 to 0.5 mm with a resin content of 20% would provide good balance between damping ratio and elastic modulus. However other particulate reinforcements could also be used with 10-15% variation in the properties. The powder morphology has an influence on wettability and the resulting properties. The damping ratio of the polymer composite can be determined using the 'Rule of Mixture' formula. Since butadiene powders provide superior damping, it could be used as secondary filler for these polymer composites.

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FIGURES

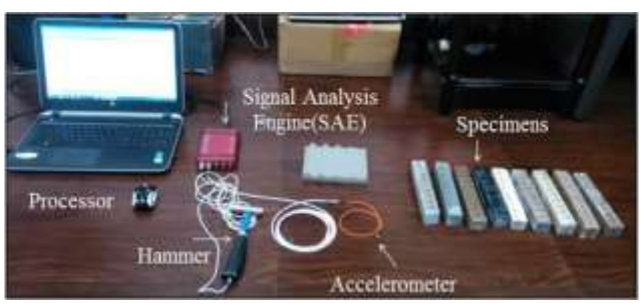

Fig.1(a). Impulse hammer test set-up

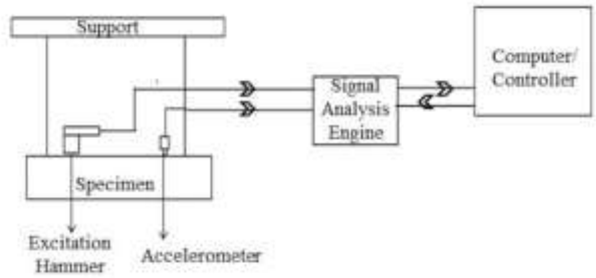

Fig.1(b). Schematic diagram of impulse hammer test

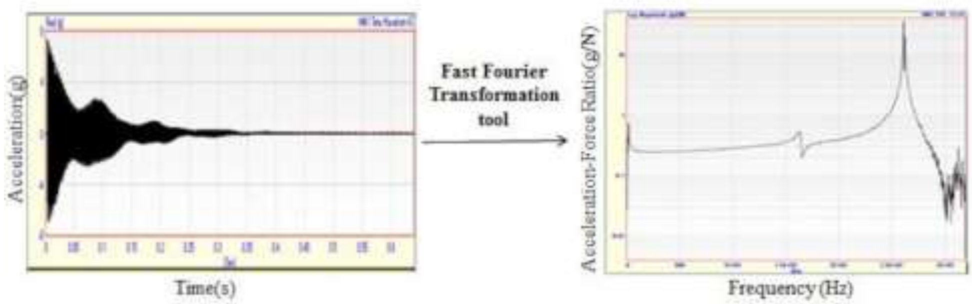

Fig.2. Conversion of signal from time domain into frequency domain by FFT analyser

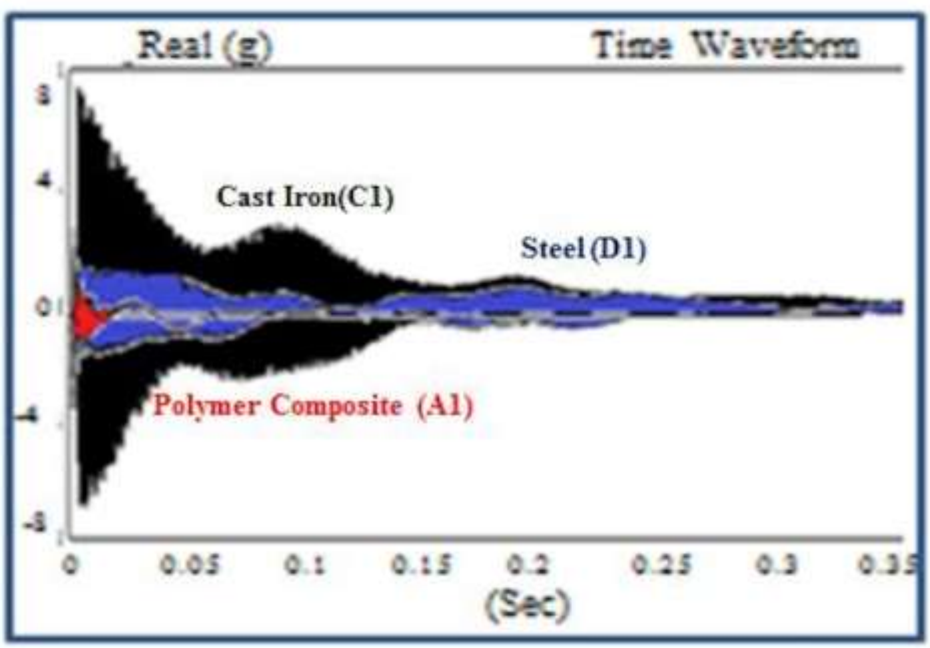

Fig.3. Vibration damping rate of polymer composite in comparison to cast iron and steel

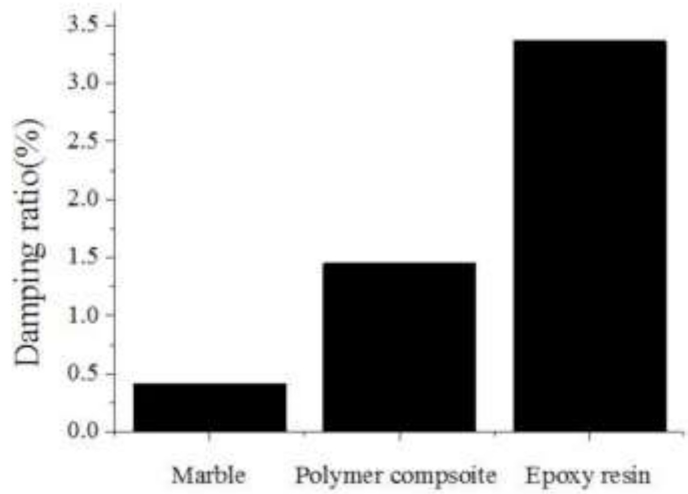

Fig.4. Comparison of damping ratio of polymer composite with its reinforcement and matrix material

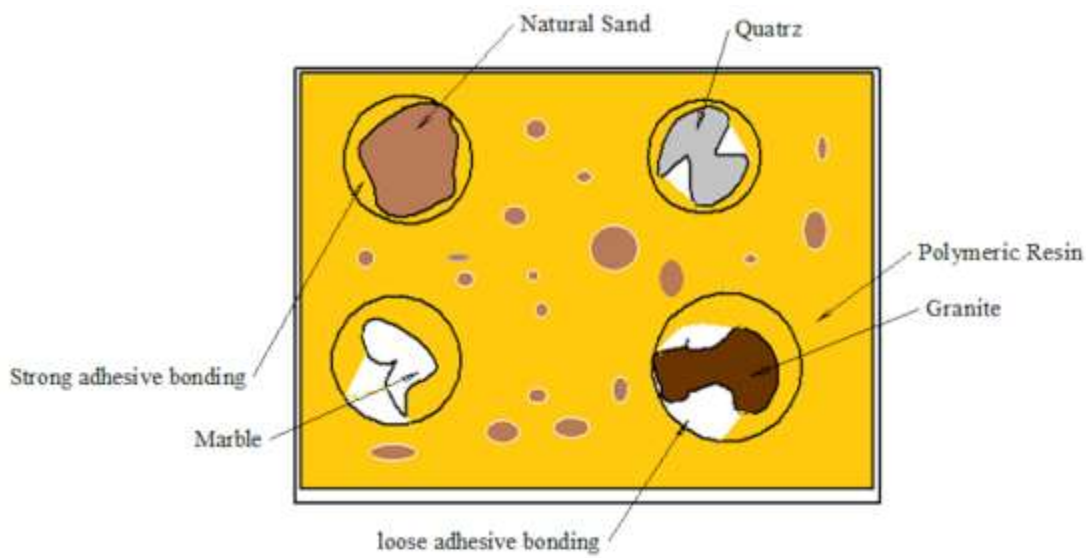

Fig. 5. Influence of surface morphology on damping ratio and elastic modulus

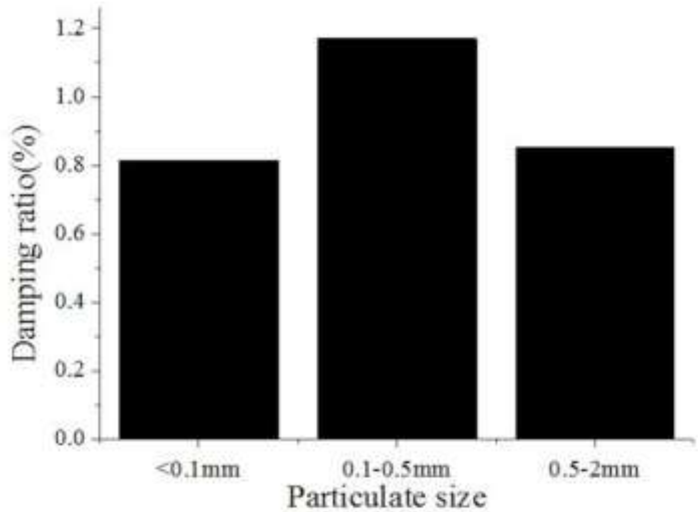

Fig.6(a).Variation of damping ratio with particulate size

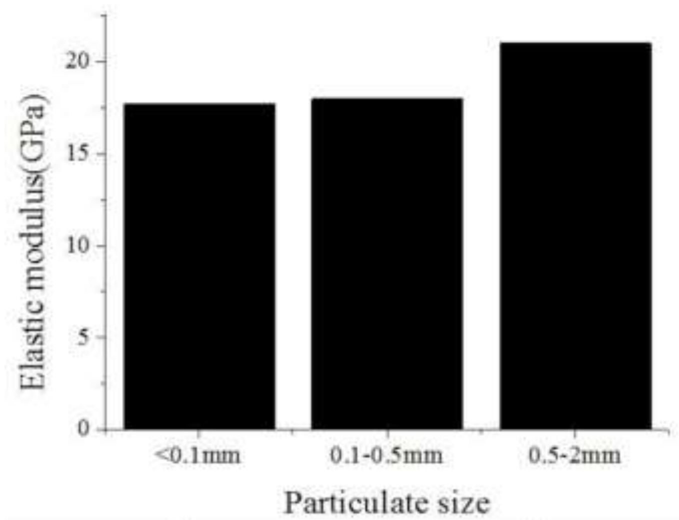

Fig.6(b). Variation of elastic modulus with particulate size

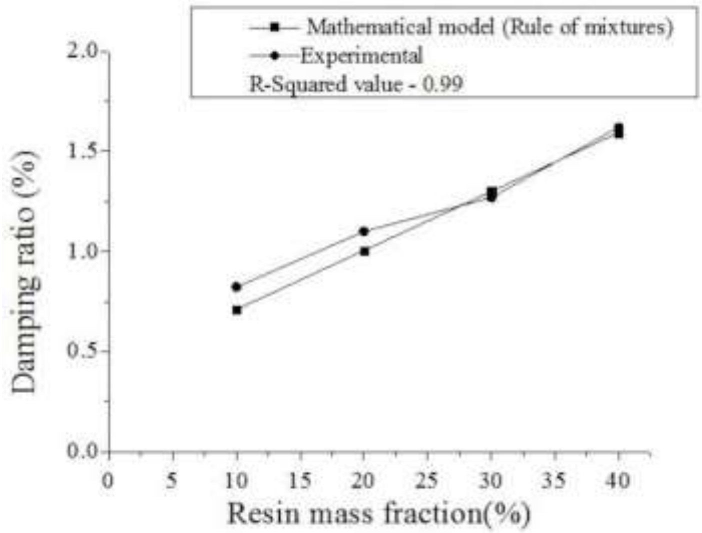

Fig.7(a).Variation of damping ratio with resin mass fraction

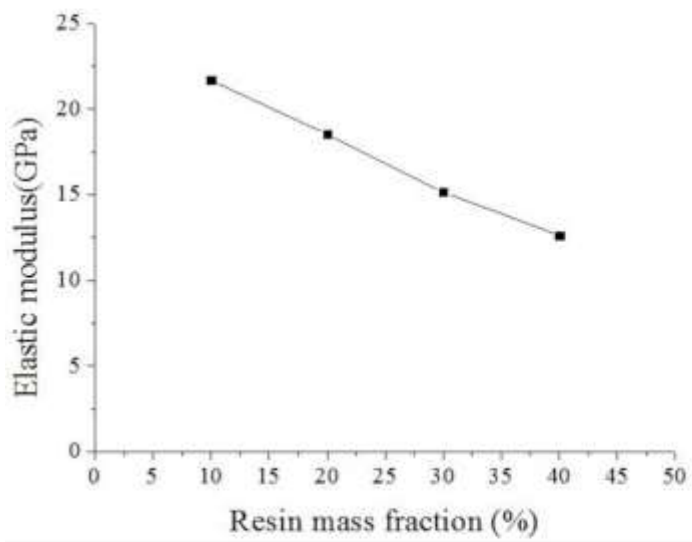

Fig.7(b). Variation of elastic modulus with resin mass fraction

TABLES

Table 1. Test specimens composition

Specimen name	Particulate type	Particulate Size	Resin mass fraction
Specimens prepared to study the influence of particulate type			
A1	Quartz powder	<2mm	20%

A2	Granite powder	<2mm	20%
A3	Natural sand	<2mm	20%
A4	Marble powder	<2mm	20%
B1	**Butadiene powder**	<2mm	20%
C1	**Cast iron**	-	
D1	**Steel(EN8)**	-	
Specimens prepared to study the influence of particulate size and size distribution			
A5	Quartz powder	<0.1mm	20%
A6	Quartz powder	0.1-0.5mm	20%
A7	Quartz powder	0.5 -2mm	20%
A8	Quartz powder	0-2mm	20%
Specimens prepared to study the influence of resin mass fraction			
A9	Quartz powder	<2mm	10%
A10	Quartz powder	<2mm	20%
A11	Quartz powder	<2mm	30%
A12	Quartz powder	<2mm	40%

Table 2. Influence of particulate type

Specimen name	Particulate type	Damping ratio(%)	Density (kg/m^3)	Natural frequency(Hz)- First bending mode	Elastic modulus(GPa)
-A1	Quartz powder	1.10	2281	1822	18.53
A2	Granite powder	0.91	2042	1775	15.55
A3	Natural sand	1.30	1762	1532	10.00
A4	Marble powder	1.10	2480	1826	20.00
B1	Butadiene powder	3.24	1124	298	0.24
C1	Cast iron	0.064	7216	2610	118.00
D1	Steel	0.046	7800	3160	189.00

Table 3. Influence of particulate size

Specimen name	Particulate size	Damping ratio (%)	Void content (%)	Elastic modulus (GPa)
A6	0.1-0.5mm	1.17	<1	18.00
A8	<2mm	1.11	<1	18.53

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